STATUS OF THE EXTENDED TRMM/GPM RADIOMETER CONSTELLATION

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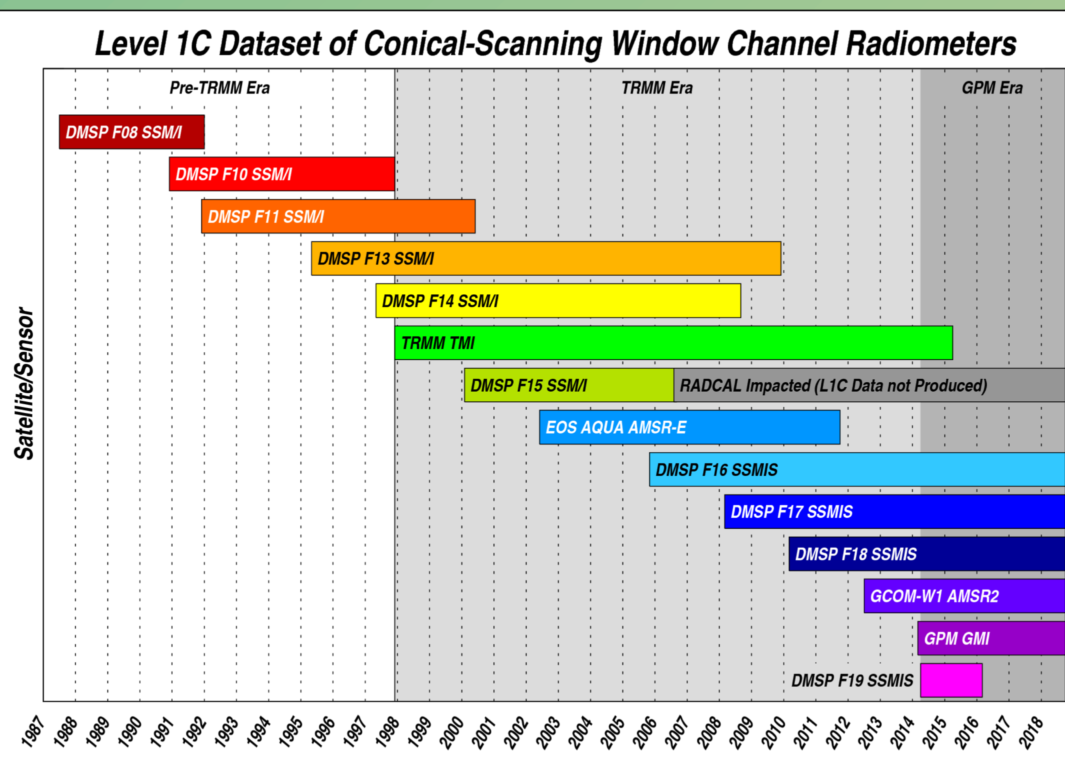
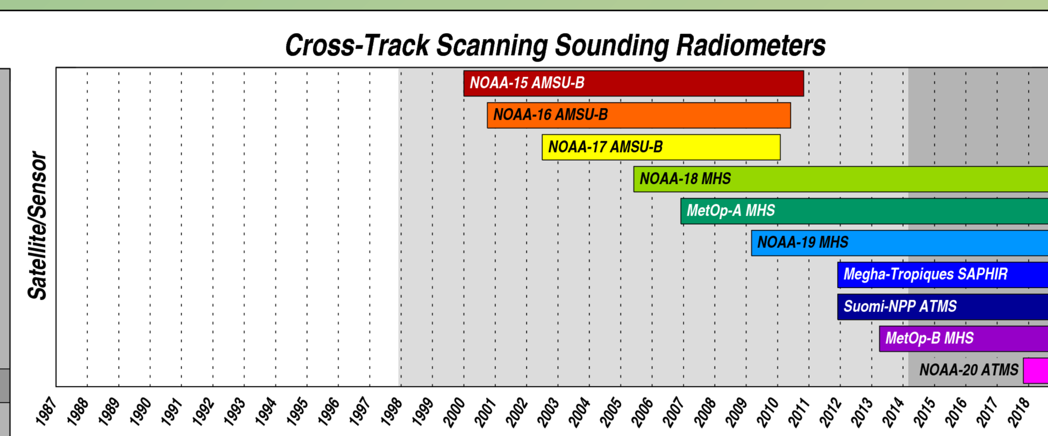
INTRODUCTION



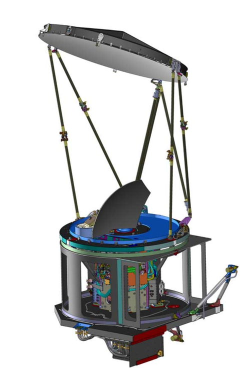


The availability of intercalibrated Level 1C data from conical-scanning window channel radiometers (left) and cross-track scanning water vapor sounding radiometers (above). The XCAL team originally focused on the GPM-era radiometers (February 2014 to the present). In late 2017, data from the TRMM-era radiometers (December 1997 through January 2014) was processed and made available. Data from the pre-TRMM SSM/I radiometers (July 1987 through November 1997) is scheduled to be processed and made available in late October or early November of 2018.

The intercalibrated Level 1 C data are the input to the GPROF operational microwave precipitation retrieval algorithm. The resulting level 2 precipitation estimates provide the high-quality global estimates used by IMERG. The Level 1C dataset is also used by a wide range of other communities for long-term climate data records and applications using a constellation of radiometers like GPM.

GPM GMI Channel Specifications

GMI Specs	10.65v/h	18.7v/h	23.8v	36.64v/h	89.0v/h	165.5v/h	183+3v	183+7v
DT x CT Res in km	32.1x19.4	18.1x10.9	16.0x9.7	15.6x9.4	7.2x4.4	6.3x4.4	5.8x3.8	5.8x3.8
Beamwidth (deg)	1.72	0.98	0.85	0.81	0.38	0.37	0.37	0.37
NEDT (K)	0.96	0.84	1.05	0.65	0.57	1.5	1.5	1.5
Beam Efficiency (%)	91.1	91.2	93.0	97.8	96.8	96.5	95.2	95.2
Uncorr Nonlinearity (K)	0.2 0.2	0.1 0.1	0.1 0.1	0.5 0.5	0.5 0.5	0.5 0.5	0.5	0.5
Band Width (MHz)	100	200	400	1000	6000	4000	3500	4500
Feedhorns	1	1	1	1	1	1	1	1
Integration Time (ms)	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6



GPM GMI provides the high-quality calibration reference for all of the instruments in the long-term radiometer constellation. The non sun-synchronous orbit of GPM regularly crosses the orbits of all of the other satellites in the GPM constellation and GMI has the same or similar channels as those used from precip retrievals from all of the imagers and water vapor sounders. The Level 1C data, however, do not include the AMSR-E/AMSR2 6/7 GHz channels or the temperature sounding channels from SSMIS or the cross-track sounders.

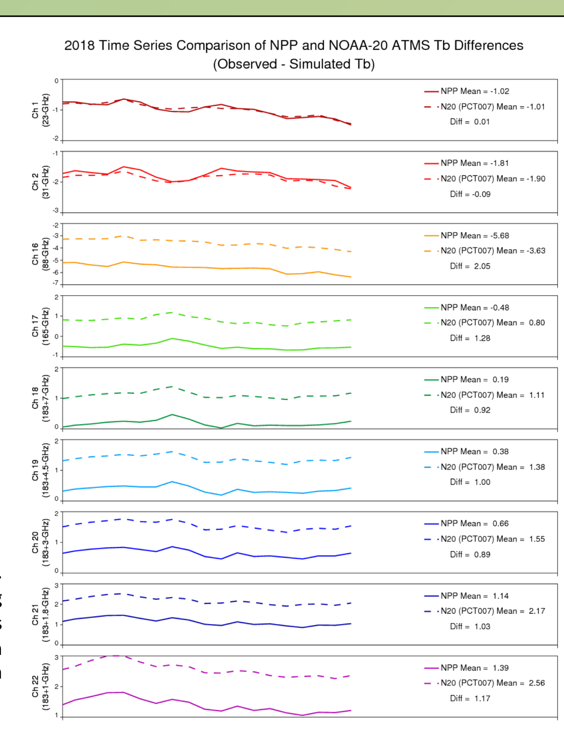
For the TRMM-era sensors, TMI was intercalibrated to GMI and then used as the calibration reference for the other instruments. For the high-frequency channels, MHS was used as the calibration reference. For the early SSM/I sensors, the results were daisy-chained back from the GMI-calibrated TMI data.

NPP AND NOAA-20 ATMS

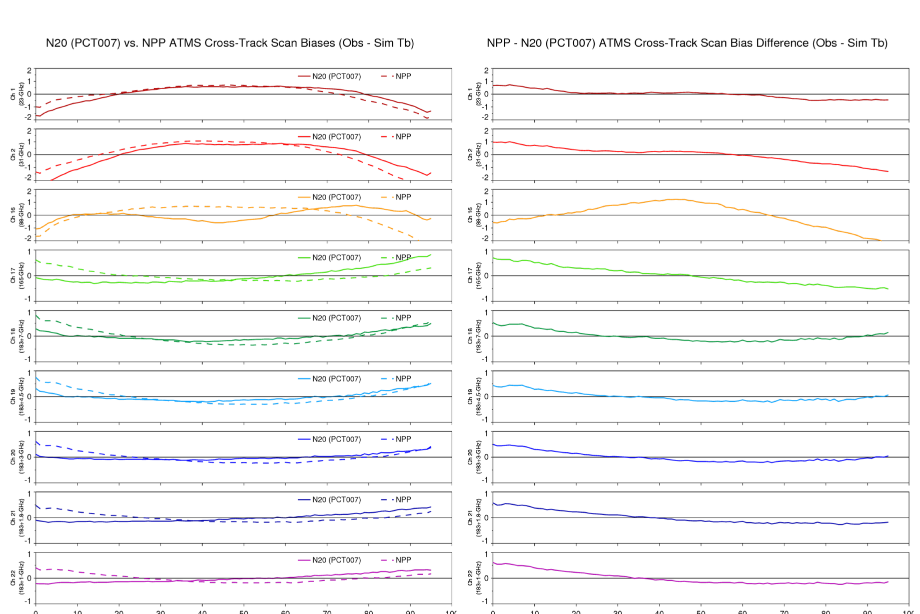
N0AA20 – NPP ATMS Tb Differences
(January 24 – July 31, 2018)

Channel	Kroodsma Differences (K)	Wilheit Differences (K)	CSU Single Difference (K)	CSU GMI Double Diff (K)	CSU Saphir Double Diff (K)
1) 23 GHz	-0.24	-0.26	-0.24	-0.17	-
2) 31 GHz	-0.32	-0.36	-0.31	-0.28	-
16) 88 GHz	1.58	1.68	1.94	2.36	-
17) 165 GHz	1.17	0.97	1.08	0.94	-
18) 183+/-7.0 GHz	1.06	0.96	0.82	0.66	0.99
19) 183+/-4.5 GHz	1.04	0.89	0.89	0.72	1.03
20) 183+/-3.0 GHz	1.09	0.98	0.81	0.60	0.98
21) 183+/-1.8 GHz	1.07	1.04	0..93	0.74	1.08
22) 183+/-1.0 GHz	1.14	1.16	1.07	0.84	1.28

Mean ATMS SDR Tb differences between NOAA20 and NPP for window and water vapor channels. Results are shown for multiple approaches. CSU (i.e. Berg) shows comparison of approaches using coincident observations GPM GMI and Megha-Tropiques SAPHIR (i.e. quad differences) as well as single difference approach (Observed – Simulated Tb). Results indicate good agreement between channels 1 and 2, with largest differences, as well as largest errors (i.e. disagreement between approaches), for channels 16 and 17.



NPP and NOAA20 ATMS Cross-Track Tb Differences



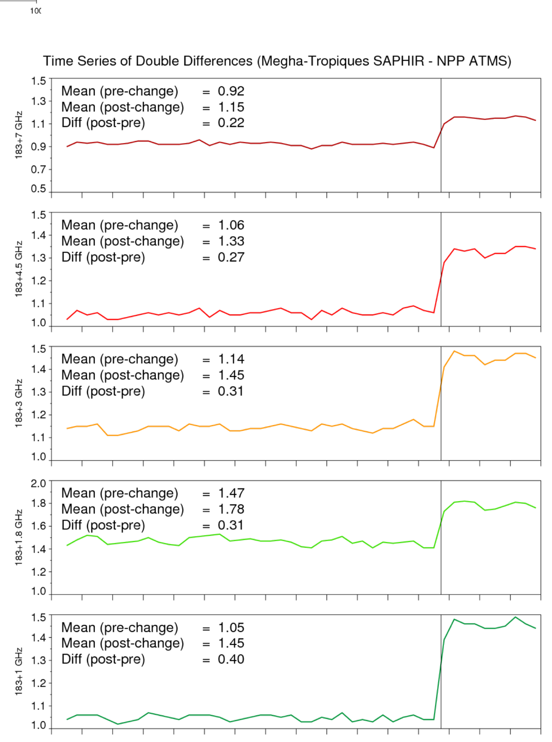
Cross-track bias patterns are shown in plots on the left for both NPP and NOAA-20 PCT007 (channels 1-2, 16-22). The differences between the two are shown in the plots on the right. Results are based on only 20 days of data (April 1-20, 2018).

Differences between the cross-scan biases for NPP and NOAA-20 ATMS remain. It is difficult to extract the cross-scan biases due only to the instrument for a cross-scan sensor since there are scan-dependent errors in the radiative transfer simulations, particularly for those channels that "see" the surface. This is due to uncertainties in the ocean emissivity model that depend on the view angle. The ATMS SDR team has updated corrections for NOAA-20 to account for an emissive reflector and nonlinearities in the detector response that have not yet been done for NPP ATMS. As a result, there are differences in the mean Tb (see above) as well as the cross-scan biases (left) and future updates to the NPP ATMS corrections are expected (see below).

NPP ATMS Calibration Change
March 8, 2017

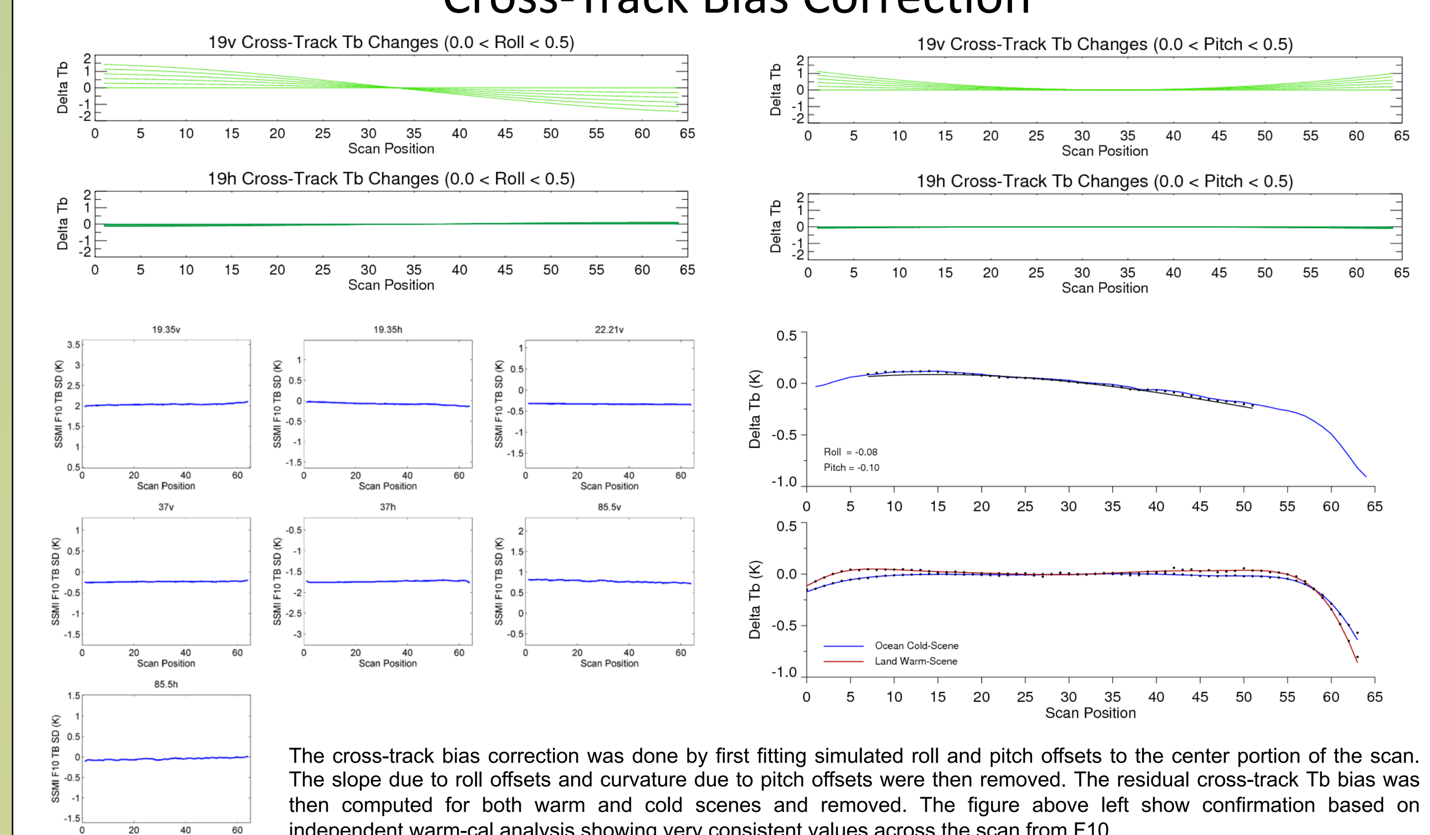
Channel	Wilheit	Berg (GMI DD)	Berg (Saphir DD)	Kroodsma
1) 23 GHz	-0.46	-0.56		-0.67
2) 31 GHz	-0.26	-0.35		-0.34
16) 88 GHz	-0.58	-0.52		-0.74
17) 165 GHz	-0.29	-0.19		-0.01
18) 183+/-7.0 GHz	-0.29	-0.24	-0.22	-0.15
19) 183+/-4.5 GHz	-0.34	-0.31	-0.27	-0.21
20) 183+/-3.0 GHz	-0.39	-0.32	-0.31	-0.28
21) 183+/-1.8 GHz	-0.36	-0.32	-0.31	-0.33
22) 183+/-1.0 GHz	-0.45	-0.40	-0.40	-0.40

Change in the NPP ATMS calibration on March 7, 2017 as determined using various intercalibration techniques. For all of the window and water vapor sounding channels analyzed, the mean Tb decreased by a few tenths to a bit of half a Kelvin



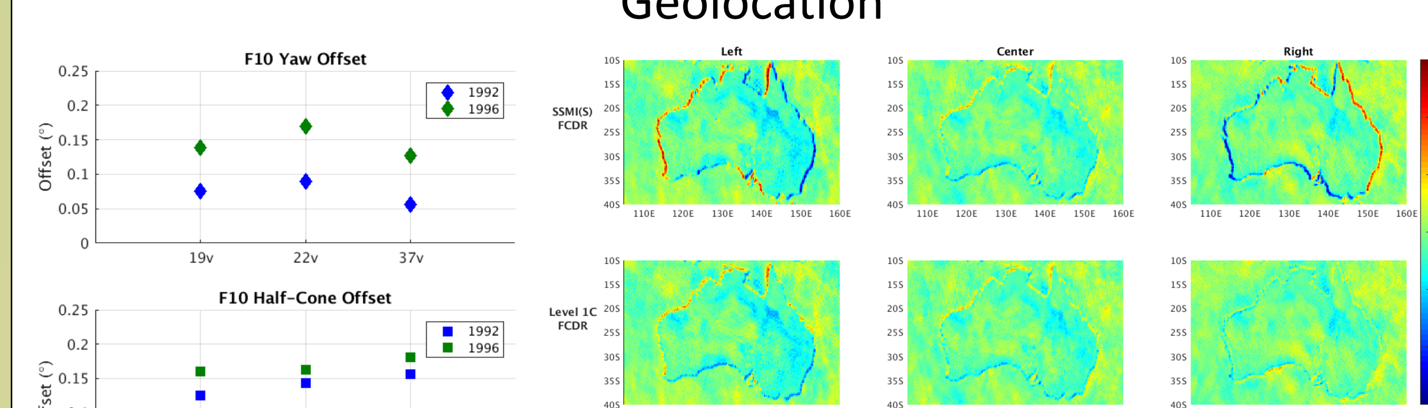
SSM/I

Cross-Track Bias Correction



The cross-track bias correction was done by first fitting simulated roll and pitch offsets to the center portion of the scan. The slope due to roll offsets and curvature due to pitch offsets were then removed. The residual cross-track Tb bias was then computed for both warm and cold scenes and removed. The figure above left show confirmation based on independent warm-cal analysis showing very consistent values across the scan from F10.

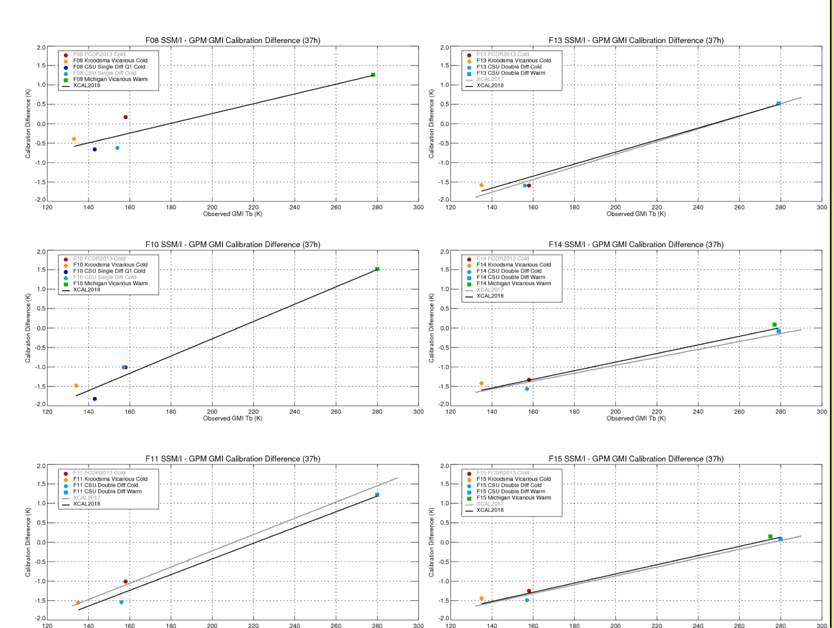
Geolocation



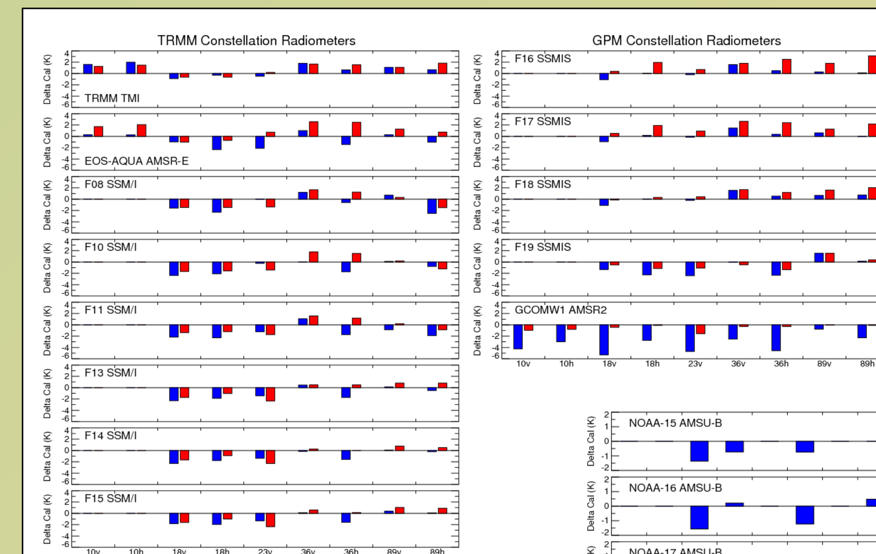
Using the roll and pitch offsets from the cross-track bias analysis, a geolocation analysis was done using a technique that compares gridded Tb maps from ascending and descending scans. Yaw and half-cone offsets were computed and the geolocation updated. The above plot shows the residual coastline errors, which are much more consistent for different parts of the scan than the previous version of the SSM/I geolocation correction.

Intercalibration

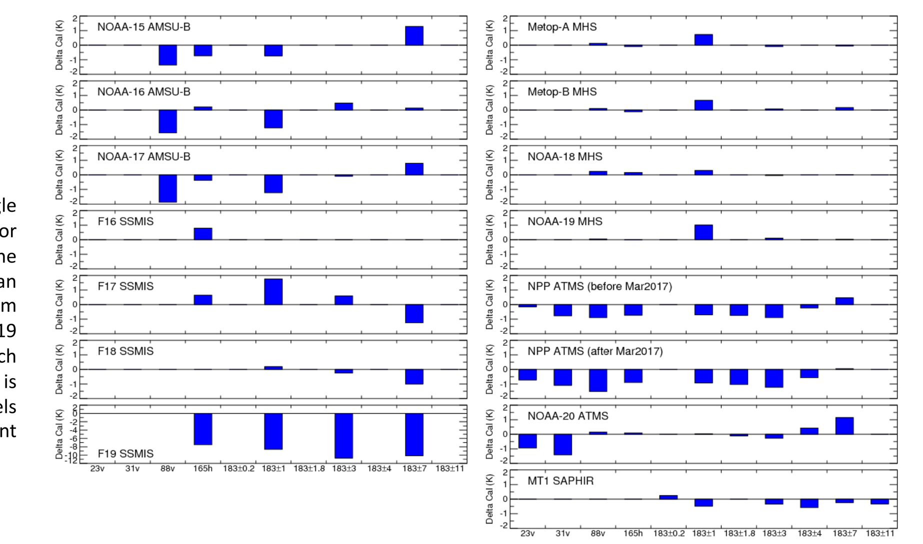
Once all of the corrections were applied, intercalibration offsets were computed for all six SSM/I sensors for both cold and warm scenes. As is standard for XCAL, multiple approaches were used over ocean and land to verify consistency and reduce residual calibration errors. For F11, F!3, F14 and F15 the calibrated TMI Level 1C data was used as the reference sensor. For F08 and F10, the results were daisy-chained using data from corresponding years. The previous XCAL calibration and the NOAA FCDR calibration offsets (cold only) are also shown for the 37h results on the right.



INTERCALIBRATION AND FUTURE SATELLITES



For the conical-scanning window channel radiometers, the XCAL team computed both cold scene (i.e. ocean) and warm scene (i.e. vegetated land) intercalibration corrections to adjust the calibration to be physically consistent with GMI. The cold and warm intercal results for all 13 imagers at are shown on the left. These are the values applied in the Level 1C intercalibration.



For the cross-track scanning water vapor imagers, a single intercalibration offset was computed by the XCAL team for each of the constellation radiometers. Generally the calibration differences are smaller for the sounders than for the imagers, which is likely due to better beam efficiency and thus smaller spillover corrections. F19 SSMIS is an exception, with the sounder channels much colder than other sensors. The suggested explanation is the presence of debris in the feedhorn for these channels resulting from the extended storage of the instrument prior to launch.

Future Radiometers including possibly CubeSats?

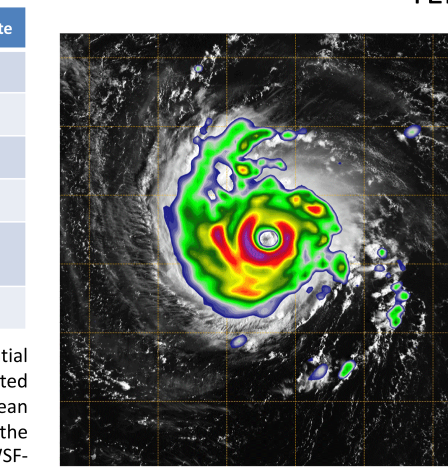
Approved and Proposed Future Radiometers

Satellite	Sensor	Status	Launch Date
MetOp-C	MHS	Approved	Dec 2018
JPSS-2 (NOAA-21)	ATMS	Approved	Dec 2021
MetOp-SG-a1	MWS	Approved	Sep 2021
MetOp-SG-b1	MWI, ICI	Approved	Dec 2022
Weather System Follow-On Microwave	WSF-M	Approved	?
GCOM-W2	AMSR3	Considered	?

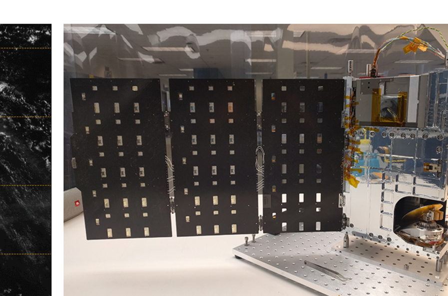
The table above shows a number of approved and potential future microwave radiometers that may be incorporated into the GPM constellation. The US JPSS and European MetOp-SG programs have several additional copies of the satellites specified above to continue into the future. WSF-M will be a modified version of GMI with no high-frequency channels, but in a higher orbit.

In addition, there are several current and planned CubeSat radiometers that may be of value to GPM at some point. TEMPEST-D (right) is a very short lived demonstration mission, but TROPICS with six satellites will be launching in the next few years.

TEMPEST-D



A first light image of brightness temperatures from TEMPEST-D overlayed on a geostationary IR image of hurricane Florence on September 11, 2018.



The 6U TEMPEST-D CubeSat satellite with its payload of a 5-channel cross-track scanning microwave radiometer and its solar panels deployed. The channels are similar to those on the Microwave Humidity Sounder (MHS) with frequencies from 89 to 182 GHz. Instrument characteristics compared to GMI are given below.

Specification	GPM GMI	TEMPEST-D
Scan Type	Conical	Cross-track
Channels	13 (10-183 GHz)	5 (89-182 GHz)
Mass	166 kg	3 kg
Power	162 W	6.5 W
Volume	1.4 x 1.5 x 3.5m	3U (10 x 10 x 30 cm)
Reflector Aperture	1.22 m	6.8 cm

SUMMARY

1. Level 1C Status
   - The Level 1C dataset has been extended back to F08 in July of 1987 and the calibration corrections and offsets have been updated for all six SSM/I instruments.
   - NOAA-20 has been added to the Level 1C data record and updates produced to account for a calibration change in NPP ATMS in March of 2017.
   - Intercalibrated Level 1C data brightness temperature data is now available from a total of 14 imagers and 10 sounders over 31+ years.
2. XCAL Activities and plans
   - Respond to sensor issues (e.g. SSMIS), calibration changes (e.g. ATMS), new sensors (e.g. MetOp-C MHS, JPSS2 ATMS…), and prepare for future sensors (e.g. MetOp-SG, Cubesats?).
   - Updates to SSMIS corrections/calibration.
   - Continue to work on quantifying residual uncertainties and coordinating with algorithm teams
3. References

   - Berg, W., R. Kroodsma, C. D. Kummerow, and D. S. McKague, 2018: Fundamental Climate Data Records of Microwave Brightness Temperatures, *Remote Sensing*, 10(8), 1306; https://doi.org/10.3390/rs10081306.
   - Berg, W. et al., 2016: Intercalibration of the GPM Radiometer Constellation, *J. Atmos. Oceanic Technol.*, 33, 2639-2654, https://doi.org/10.1175/JTECH-D-16-0100.1.

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